APPENDIX 3-2

WATER QUALITY MODEL TECHNICAL MEMORANDUM

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BLACK & VEATCH.

TECHNICAL MEMORANDUM

South Florida Water Management District — B&V Project 141522.321
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Task 5.3.2.3.5 Water Quality Model Technical Memorandum
Water Quality Model

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From: Andy Andrews

1. BACKGROUND AND OBJECTIVES

1.1 Background

Task 5.3.2., Water Quality Model, of Work Order 5, requires Black & Veatch to develop a computer model for predicting pre-impoundment water quality in the EAA A-1 Reservoir. It is important to estimate potential phosphorus levels in the reservoir because all new CERP projects much provide assurances that water quality will not be negatively impacted. High concentrations of phosphorus entering the reservoir from the New North River and Miami canals may result in excessive algae growth in the form of floating algae, which could be considered aesthetically undesirable.

Technical Memorandum 1, Selection of Water Quality Model, evaluated three models for potential application to the A-1 Reservoir:

- DMSTA2
- Lake Okeechobee Water Quality Model
- CE-QUAL

DMSTA2 was selected primarily because it is expected to provide the best estimate of long-term phosphorus removal in the reservoir since the model has been calibrated to numerous Florida reservoirs.

As part of the PIR/EIS, the USACE is currently conducting a water quality assessment of the EAA reservoirs using a water quality model developed by Wetland Solutions, Inc. The model was not considered as an alternative for this study, since it was not available.

1.2 Objectives

The objective of this task is to develop a water quality model of the A-1 Reservoir, which will predict phosphorus concentrations in the water stored and released and amounts of phosphorus settled and deposited in the reservoir bottom sediments.

The objective of this memorandum is to document the results of Work Order 5, Subtask 5.3.2.3 Develop Water Quality Model.

2. DMSTA FOR RESERVOIRS

2.1 Description

The Dynamic Model for Stormwater Treatment Areas (DMSTA) was developed by Dr. Bill Walker and Dr. Bob Kadlec under contract with the US Department of Interior and the US Army Corps of Engineers to support the design of wetland treatment areas that would be capable of removing phosphorus from stormwater runoff from the Everglades Agricultural Area and Lake Okeechobee releases. DMSTA simulates daily water and mass balances in a user-defined series of wetland treatment cells, each with specified morphometry, hydraulics, and phosphorus cycling parameters.

Up to six treatment cells can be linked in series and/or parallel to reflect compartmentalization and management to promote specific vegetation types. Each cell is further divided into a series of continuous stirred tank reactors (CSTRs) to reflect residence time distribution.

Water-balance terms for each cell include inflow, bypass, rainfall, evapotransportation, outflow, and seepage in and out of a cell. Parameter estimates for the phosphorus cycling model were developed for various vegetation types.

DSTMA was calibrated to over 100 datasets derived from experimental tanks, field test cells, natural wetlands, operating Stormwater Treatment Areas (STA), wastewater treatment wetlands, and a few lakes north of Lake Okeechobee. Most of these datasets represented relatively shallow marshes dominated by emergent or submerged vegetation. The model is coded in Visual Basic for Applications. The user interface is an Excel workbook.

Compared with typical marsh treatment areas in the STAs, CERP storage reservoir designs, such as the EAA A-1 Reservoir, tend to have greater mean depths, greater variations in depth, and longer water residence times. These factors can be expected to have significant effects on vegetation communities, phosphorus dynamics, and model calibrations. Currently, STAs are operated at a static water depth of 1.2 to 1.5 ft. Deteriorations in vegetation integrity and performance have been observed in cells with prolonged water depths exceeding 2.5 to 3 ft. Current designs for CERP reservoirs have maximum depths ranging from 6 to 12 ft. The expected maximum operating depth for the A-1 Reservoir is about 12 ft. The reservoir embankment will be designed to store the Probable Maximum Precipitation and to accommodate wave run-up above the 12 ft operating depth.

DMSTA was enhanced by Dr. Bill Walker to support its application to deeper storage reservoirs. DMSTA Version 2 (DMSTA2) and was released in June 2005. DMSTA2 was calibrated and tested using existing datasets from the following sources:

- Burns & McDonnell (Under contract to ADA Engineering), "Water Quality Impacts of Reservoirs - Task 3 Analysis of Datasets", prepared for South Florida Water Management District, August 2004. (8 datasets, daily time series)
- Wetland Solutions, Inc. (WSI), "Lake Okeechobee Watershed Project - Calibration of DMSTA Model for Use North of Lake Okeechobee", prepared for HDR, Inc., November 2003. (4 datasets, daily time series)
- W.W. Walker, "Estimation of a Phosphorus TMDL for Lake Okeechobee, prepared for Florida Dept of Environmental Protection & U.S. Department of the Interior, December 2000. (2 datasets, monthly time series)
- W.W. Walker & K. Havens, "Development & Application of a Phosphorus Balance Model for Lake Istokpoga, Florida", Lake & Reservoir Management, Vol. 19, No 1, pp. 79-91, 2003. (1 dataset, daily time series)
- USEPA., "A Compendium of Lake & Reservoir Data Collected by the National Eutrophication Survey in Eastern, North-Central, & Southwestern United States", Working Paper No. 475, Corvallis Environmental Research Lab and Environmental Monitoring & Support Lab, Las Vegas, September 1978. (28 Florida lakes sampled in 1973, for testing of steady-state model)
- On June 3, 2005, a B&V Water Resources Engineer attended a workshop conducted by Dr. Walker, who presented the theory and use of DMSTA2.

2.2 Application DMSTA2 to the A-1 Reservoir

Application of DMSTA2 to the A-1 Reservoir involved the following steps:

- Time series of inflows and outflows to the A-1 Reservoir were imported from the ECP 2010 model (Appendix 5-21), which were also used in the B&V Water Balance Model (WBM). Inflows included available flows from the New North River Canal (NNR) at Pump Station 370; available flows from the Miami Canal (MC) at Pump Station 372; and rainfall. Outflows included releases to agricultural and environmental areas, evapotranspiration, seepage, and any discharges when the water level exceeds the expected operating depth of 12 ft (365 cm).
- Time series of phosphorus concentrations associated with the (NNR) and the MC will be based on monthly average concentrations developed by Burns & McDonnell (B&M) as part of the Regional Feasibility Study (B&M 2005). Task 1.3, Historical Inflow Volumes and Total Phosphorus Concentrations by Source, June 27, 2005.
- The times series described above will be imported to DMSTA2, which will produce continuous daily simulations of water and phosphorus mass balances over a long-term simulation period.

3. INPUTS TO DMSTA2

3.1 Area and Volume

Inputs to DMSTA2 that describe the area and volume of the A-1 Reservoir are in terms of surface area and outflow weir depth, which was set at 365 cm (12 ft). DMSTA2 assumes that water will be released from the reservoir if the depth exceeds 365 cm. The surface area of the reservoir was set at a constant 64 km2 (about 16,000 acres).

3.2 Canal Flows

Water stored in the A-1 Reservoir will be supplied from the NNR and MC. The ECP 2010 model (Appendix 5-21) provided times series of average daily flows for each of these sources for a 36 years simulation period from 1965 to 2000. These time series were inputs to DMSTA2.

Over the 36 year simulation period, the sum of the two sources averaged 1.67 million cubic meters per day (million m3/day) or 680 cfs. 66 percent of the total canal inflow came from the NNR.

Figure 1 shows the total average annual canal inflow for the 36 year simulation period.

Phosphorus concentrations associated with flows in the NNR and MC were based on monthly average concentrations developed by the previously cited B&M Regional Feasibility Study. Table 1 summarizes the monthly average concentrations from the B&M study

The time series of concentrations in Table 1 were repeated for each year of the simulation. Concentrations associated with the time series of average daily flows for a particular month were set equal to the monthly average concentrations for the corresponding month. For example, the phosphorus concentrations of all of the NNR January daily flows for the 36 year simulation were equal to 70 ppb.

Figure 2 shows the flow-weighted average annual inflow phosphorus concentrations associated with the total canal inflows. The average concentration for the simulation period is 82 ppb.

3.3 A-1 Reservoir Demands

The A-1 reservoir will store water that will be released to meet irrigation and environmental demands. The ECP 2010 model (Appendix 5-21) provided times series of average daily flows for each of these demands for the 36 years simulation period. These time series were input to DMSTA2.

Over the 36 years simulation period the ECP 2010 model indicated that the irrigation and environmental demands averaged 0.59 million m3/day and 0.68 million m3/day or 244 cfs and 280 cfs, respectively.

Figure 3 shows the annual average irrigation (Release 1) and environmental (Release 2) demands.

3.4 Rainfall and Evapotranspiration

Rainfall and evapotranspiration data were obtained from the ECP 2010 model (Appendix 5-21) and input to DMSTA2. The average rainfall and evapotranspiration rates for the simulation period were 0.35 cm per day (50.3 inches per year) and 0.31 cm per day (44.5 inches per year) or 89.6 cfs and 77.4 cfs, respectively. The difference between rainfall and evapotranspiration, 0.04 cm per day (5.8 inches per year), is the net rainfall applied directly to the reservoir. This amount is approximately 2 percent of the inflow from the canals.

Figure 4 shows the average annual rainfall and evapotranspiration for the 36 year simulation period.

3.5 Seepage

DMSTA2 calculates seepage outflow from the reservoir based on a user defined rate in cm per day per cm of reservoir depth. As the reservoir depth increases so does the rate of seepage. DMSTA2 also allows a user to define potential seepage re-cycling back to the reservoir as a fraction of the predicted seepage outflow.

Using hydrologic and hydraulic models, B&V predicted seepage rates for several depths of seepage cut-off walls. The seepage outflow rate and return fraction in DMSTA2 was based on the B&V seepage and return rates for a 34 ft cut-off wall and a seepage collection canal with a bottom elevation 10 ft below the bottom of the reservoir.

4. DMSTA2 RESULTS

DMSTA2 performed water and phosphorus mass balances for each day of the 36 year simulation period. The water balance, which was similar to the B&V WBM, was based on the following equation:

Flow inputs – Flow outputs = Change in Reservoir Storage

Where

Flow inputs included canal inflows, rainfall, and seepage return flows

Flow outputs included releases to meet irrigation and environmental demands, seepage, evapotranspiration, and releases when the reservoir depth exceeded 12 ft (365 cm).

Changes in reservoir storage were equated to changes in water depth

It should be noted that DMSTA2 automatically sets irrigation and environmental releases equal to zero when the reservoir depth was less than 6 cm.

DMSTA2 conducts a similar daily mass balance on phosphorus (P) in the reservoir based on the following equation:

P loading inputs – P loading outputs = Change in P storage in the water column

Where

P loading (water volume times P concentration) inputs are associated with the canal inflows, rainfall, and seepage return flow

P loading outputs are associated with irrigation and environmental releases, seepage, and releases when the reservoir depth exceeds 365 cm

Changes in P storage include loss of P in the water column due to uptake of P by biomass, loss of P to the bottom sediments from biomass settled from the water column, and gain of P back to the water column from P recycled from the bottom sediments

4.1 Reservoir Water Depth

The net result of the water mass balance is the reservoir depth at any time during the simulation. During the 36 year simulation the average depth of the reservoir was 327 cm (10.7 ft). The maximum average annual water depth of 369 cm (12.1 ft) occurred in 1995, and the minimum average annual water depth of 236 cm (7.7 ft) occurred in 1965.

Figure 5 shows the average annual water depth for the 36 year simulation period.

4.2 Phosphorus

It is important to estimate potential phosphorus levels in the reservoir because all new CERP projects must provide assurances that water quality will not be negatively impacted. DMST2 was used to estimate the impact of the A-1 reservoir by providing mass balances of phosphorus for the 36 year simulation period.

Between 1965 and 2000, the average total loading to the reservoir was 65.2 x 10^3kg per year. Of that, 76 percent came from the canals, while only 3 percent and 21 percent were from rainfall and re-cycled seepage, respectively. DMSTA2 assumed that phosphorus in seepage from the reservoir would not be removed in the underlying soil. Since adsorption of phosphorus by the soil is possible, phosphorus loading back to the reservoir may be somewhat less than predicted.

The total phosphorus leaving the reservoir during the simulation period was 56.7 x 10^3kg per year. Of that, 27 percent and 32 percent were released to meet irrigation and environmental demands. Another 32 percent of the total releases were from seepage, although 75 percent of the seepage released was recycled back to the reservoir. An additional 9 percent of the flow leaving the reservoir was from discharges during periods when the water surface elevation exceeded the operating depth of 12 ft. The flow weighted average concentration of phosphorus in the releases was 68 ppb during the simulation period compared to an average of 82 ppb associated with the inflows.

The difference between the phosphorus inflow loading and outflow loading is the amount of phosphorus deposited or buried in the reservoir sediments, or an average of 8.5 x 10^3kg per year for the simulation period. If this amount is subtracted from the average annual total loading from the canals (49.6 x 10^3kg per year – 8.5 x 10^3kg per year.), the reservoir is estimated to achieve an average 17 percent reduction in the phosphorus loading from the canals.

Table 2 is a summary of the phosphorus mass balance for the simulation period. The table also includes mass balances for 1983, one of the years of the highest phosphorus loading, and for

1975, one of the years of the lowest phosphorus loading. In 1983 and 1975, the reservoir reductions in phosphorus loadings are estimated to be 9 percent and 34 percent, respectively. The DMSTA2 results indicated relatively high phosphorus removal at low depths and relatively low removal at high depths.

DMSTA2 has the capability to provide “Conservative” simulations compared to the “base” simulations previously described. The Conservative simulation uses a phosphorus removal rate (K) that is the lowest 10 percentile of the calibrated K values. The Conservative simulation indicated a 13 percent reduction in phosphorus for the simulation period compared to the 17 percent reduction for the base simulation.

Appendix 3-4 DMSTA2 Executable Case Files includes all the files developed for this study. Case 1A-9 is the final model run and includes the time series of average daily canal flows, releases, and other inputs used in DMSTA2 for the 36 years simulation period and the model results, including the flow and phosphorus mass balances.

4.3 Algae and Dissolved Oxygen

Given the highly variable water depths in the reservoir over an annual cycle, phytoplankton (single cell algae) is expected to be the predominate form of algae. Although algae growth in the reservoir is desirable because algae remove phosphorus, potential floating algae (blue green) during some years may be aesthetically unpleasing but would probably not be considered to be a nuisance. Any potential excessive growth of algae is not expected to interfere with the operation of reservoir gate structures or pumps.

Wind energy should be sufficient to keep the water vertically well-mixed resulting in dissolved oxygen near saturation concentration most of the time. At the upper operating depths, approaching 12 ft, some minor thermal stratification may occur, but a significant depletion of dissolved oxygen is not expected at any time unless the bottom soil has an unusually high sediment oxygen demand.

5. SUMMARY AND CONCLUSIONS

5.1 Summary

The objective of this task is to develop a water quality model of the EAA A-1 Reservoir, which will predict phosphorus concentrations in the water stored and released and amounts of phosphorus settled and deposited in the reservoir bottom sediments.

DMSTA2 was selected to conduct a 36 year simulation of the reservoir primarily because it is expected to provide the best estimate of long-term phosphorus removal since the model has been calibrated to numerous Florida reservoirs.

Time series of inflows and outflows to the reservoir were imported to DMSTA2 from the ECP 2010 model (Appendix 5-21). The same time series were also used in the B&V Water Balance Model. Inflows included available flows from the North New River Canal at Pump Station 370; available flows from the Miami Canal at Pump Station 372; and rainfall. Outflows included releases to agriculture and environmental areas, and evapotranspiration.

Phosphorus concentrations associated with flows in the NNR and MC were based on monthly average concentrations developed by the Burns & McDonnell Regional Feasibility Study (B&M 2005)

During the 36 year simulation period provided by the ECP 2010 model (Appendix 5-21) results, the average depth of the reservoir was estimated by the DMSTA2 model to be 327 cm (10.7 ft).

During the 36 year simulation, the difference between the phosphorus inflows and outflows, which is the amount of phosphorus deposited or buried in the reservoir sediments, averaged 8.5x 10^3kg per year. This burial rate indicates that the reservoir is expected to achieve an average 17 percent reduction in the phosphorus loading from the canals. A “Conservative” estimate of phosphorus reduction is 13 percent.

5.2 Conclusions

The A-1 Reservoir will not negatively impact water quality in the Everglades Agricultural Area. Phosphorus contained in the supply canals could be removed in the reservoir as simulated by the DMSTA2 model. Phytoplankton (single cell algae) will be responsible for most of the phosphorus removal. However, periodic episodes of floating blue green algae may be aesthetically unpleasing. Significant depletion of dissolved oxygen in the reservoir is not expected. Wind energy should be sufficient to keep the water vertically well-mixed resulting in dissolved oxygen near saturation concentration most of the time.

6. REFERENCE

Burns & McDonnell (Under contract to ADA Engineering) . Regional Feasibility Study, Task 1.4 Historical Inflow Volumes and Total Phosphorous Concentration by Sources. South Florida Water Management District. 27 June, 2005.

TABLES

Table 1 Average Monthly Phosphorus Concentrations, parts per billion

Source	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
NNR	70	65	55	76	107	85	77	62	68	67	114	92	78
Miami Canal	60	46	47	77	77	77	116	94	109	117	119	69	84

Table 2 Phosphorus Mass Balance

INFLOW	**1983** 10^3 **kg P/yr**	**1975** 10^3 **kg P/yr**	**1965-2000** 10^3 **kg P/yr**
Canals	98.2	21.2	49.6
Rainfall	2.1	2.1	2.1
Seepage Recycle	16.3	11.2	13.5
Total	**116.6**	**34.5**	**65.2**
OUTFLOW			
Irrigation Releases	20.3	8.8	15.1
Environmental	57.4	0.6	18.2
Seepage	21.8	14.9	8.3
Discharges	8.2	3.0	5.4
Total	**107.7**	**24.3**	**56.7**
DEPOSITION	**8.9**	**7.2**	**8.5**
Reduction	**9%**	**34%**	**17%**
Reduction-Conservative Case	**–**	**–**	**13%**

FIGURES

Figure 1 Annual Canal Inflows to DMSTA2

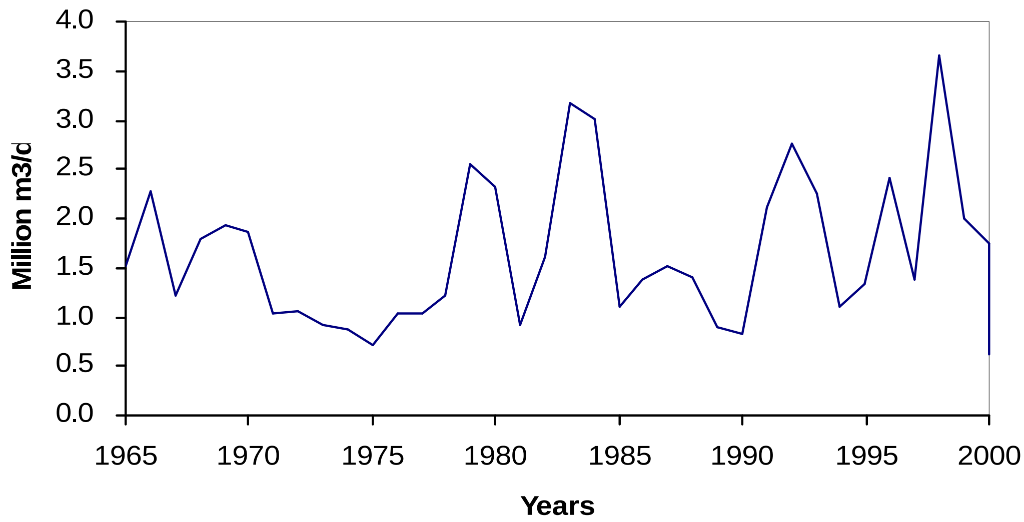

Figure 2 Average Annual Phosphorus Concentrations in Canal Flows

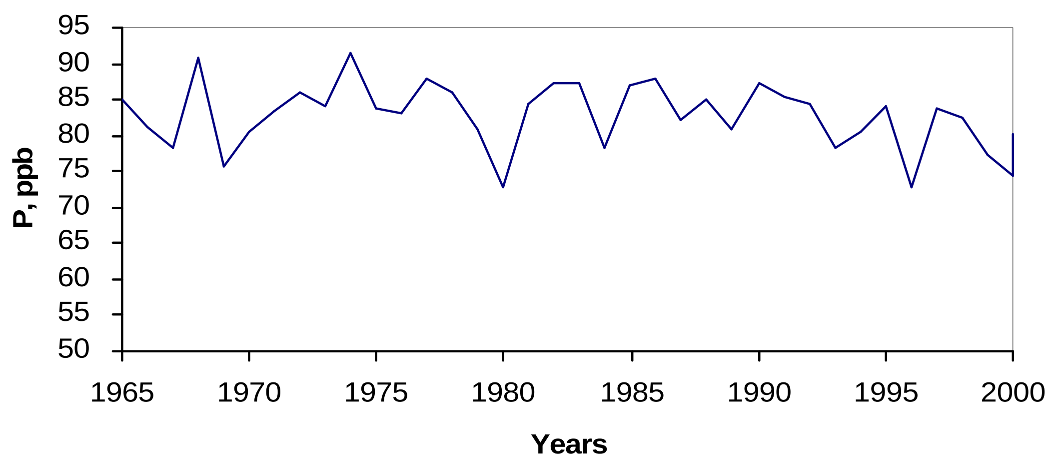

Figure 3 Irrigation and Environmental Demands

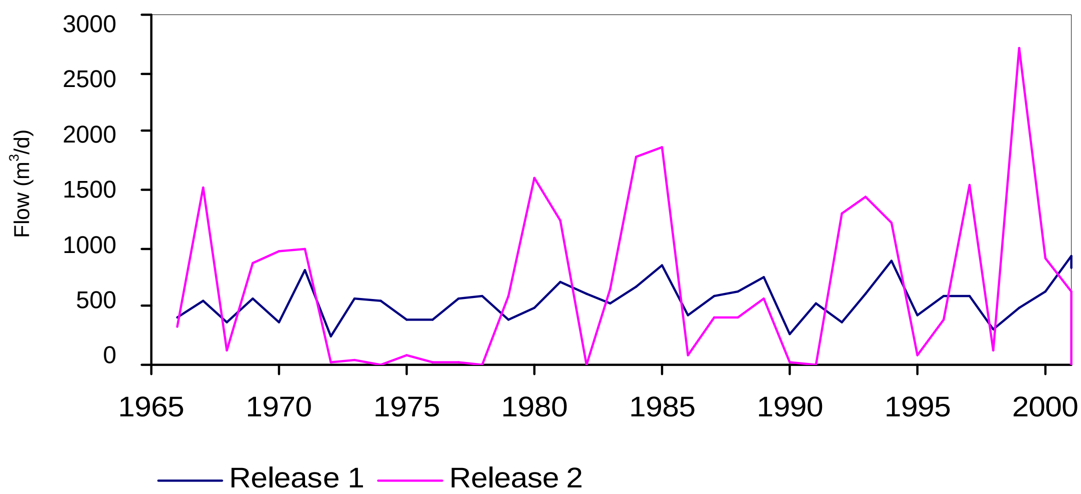

Figure 4 Average Annual Rainfall and Evaporation

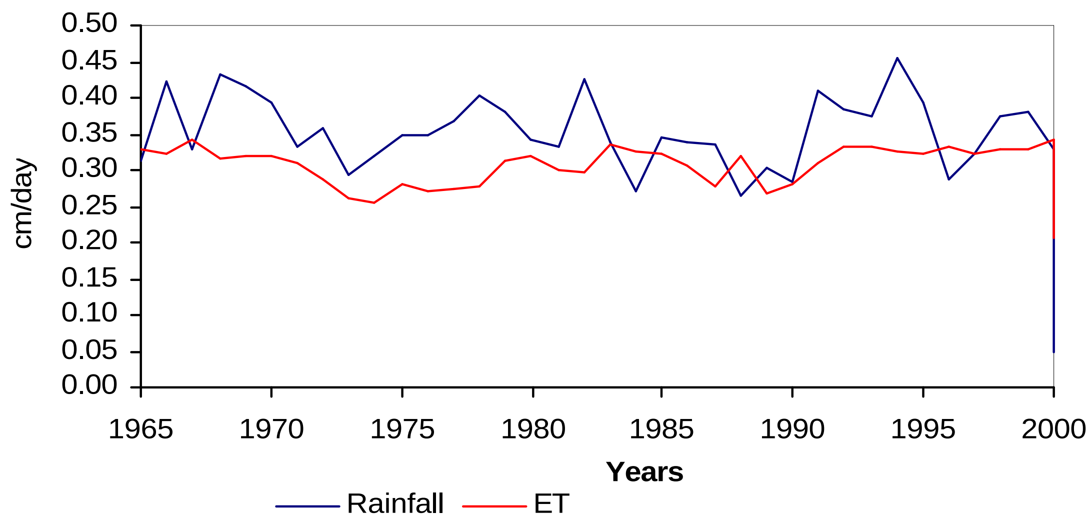

Figure 5 Average Annual Water Depth